Characterization of Uncertainty in Low Frequency Active Sonar

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LONG-TERM GOALS

The goals of this project are to characterize and evaluate the effects of uncertainty on low frequency impulsive active sonars of the type exemplified by Distant Thunder (DT) or Extended Echo Ranging (EER). This project is a component of the UNITES effort aimed at (i) comprehending uncertainty in the ocean environment and characterizing its impact on tactical sonar performance, and (ii) providing the Navy with guidance for understanding sonar performance in the littoral.

OBJECTIVES

Performance prediction models are used to characterize expected operational capabilities of sonars. In the best situation, uncertainty of sonar performance can be effectively described by the signal-to-interference ratio (SIR) environmentally-induced probability density function (SIRE-PDF), which is the distribution of the difference between measured and modeled SIR, and describes the predictive capability of the present model (that is, for specific location and time) with respect to actual performance. Thus, the SIRE-PDF accounts for the inherent unmodeled variability of the environment and is a probabilistic description of intrinsic environmental uncertainty. The focus of this effort is to formulate and evaluate significant examples of SIRE-PDF for low frequency impulsive active sonars.

APPROACH

To establish the interference component of the SIRE-PDF, a data-based approach will be followed using environmentally well characterized reverberation and noise data selected from the Area Characterization Tests (ACT I, II and III) obtained under the DARPA Adverse Environments program from 1992-1997 and from SHAREM 126 under the NAVSEA MAASW(DT) program in 1998 in operationally significant areas (Korea Strait in '96 and East China Sea in '98). These data will be used to determine the distribution of the difference between measured and modeled reverberation or noise interference. To establish the signal component of the SIRE-PDF selected high signal-to-background signal excess measurements and target echoes from the Area Characterization Tests and from DT exercises (SHAREM 122, 126, 127, 130 and 136) since 1997 will be used. These data will be used to determine the distribution of the difference between measured and modeled target strength. The signal-to-interference PDF can be constructed from the distributions of measured minus modeled signal and interference [1].

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The initial work during the first year effort focused on characterization of the variability of interference, i.e., reverberation and noise, with particular emphasis on description of reverberation for active sonar. Reverberation modeling uncertainty involves stochastic variability of reverberation scattering strength and of transmission loss to and from the scattering region, plus more systematic uncertainty involving spatial variations of scattering strength and transmission factor. Current effort on specifying uncertainty in interference is focused on determination of the effects of receive array beamforming on the statistics of reverberation and noise interference.

The main focus of current effort has been on the variability of active sonar received signal-to-interference for a non–fluctuating target. In addition to the variability and uncertainty of the interference, which had been the subject of the first year effort, the uncertainty and variability of signal-to-interference will depend both upon the variability of the transmission loss to and from the target and also upon the variability of the target. As noted, for the current effort the variability of the target has been removed from the equation, so that the expected variation of the signal numerator of the signal-to-interference ratio will be associated with the temporal and spatial variability and uncertainty of transmission loss.

Selection of the data for analysis, definition of the processing procedure and performance modeling is under the direction of Peter Cable (BBN); and data processing and interpretation are under the direction of Jay Pulli (BBN) and Rob Gibson (BBN). The direction and results of the analysis process have been coordinated with the work at OASIS, our UNITES team colleagues in this effort, for further analysis under the direction of Philip Abbot.

WORK COMPLETED

During FY03 the principal effort focused on the analysis and interpretation of environmentally associated signal-to-interference variability experienced in the low frequency broadband active sonar signal excess measurements conducted during Area Characterization Test I (ACT I) performed in the Gulf of Mexico in 1992. During ACT I, measurements of echo repeater signals responding to broadband explosive sources of two types (designated LO and S) had been recorded on bottom mounted horizontal and vertical receiving line arrays in the band 100 Hz to 1 kHz. The recorded data consisted of target (i.e., echo repeater) echoes for five effectively fixed bistatic geometries; also recorded were data to separately determine, for each ping, source-to-target and target-to-receiver transmission losses and background levels at the receiving arrays. Supporting environmental data, including sound speed profiles, ocean current at the vertical receiving array and wind speed were also recorded at discrete intervals during the ACT I runs.

The recorded echo, interference and transmission data were first processed to obtain integrated energy levels using integration epochs consistent with sonar processing parameters. The processed ACT I signal excess data were entered into spreadsheet files to permit a complete statistical analysis of the echoes, and transmission and interference records at the sonar equation level. Statistics of the signal excess data were computed to separately determine the temporal and spatial variability of the echo signal-to-interference. In this regard it should be noted that processing parameters appropriate for impulsive broadband channel-spread signals (as encountered in ACT I) were used in the analysis. These parameters (e.g., time-bandwidth products ≥ 50) insure that the echo-to-interference fluctuations associated with stochastic variability will be small (typically fractions of dB). Both temporal, that is ping-to-ping, variability statistics using fixed geometry data and spatial variability statistics using different monostatic/bistatic geometries were computed. For this latter purpose, approximations implicit in the shallow water reverberation limited sonar equation were first shown to be valid for these experimental conditions and were then invoked to account adjust for target-receiver range changes with different geometries.

The observed signal-to-interference temporal variability was correlated with the measured transmission loss variability. In addition a search was made for evidence of systematic dependence of signal-to-interference variability on environmental spatial inhomogeneity. Finally, an analysis was conducted of potential systematic and random measurement or experiment induced errors that could lead to observed signal-to-interference variability.

Initial results of these studies were reported in the Capturing Uncertainty DRI Review and Planning meeting in Providence, RI during June 2003. In addition a paper "Environmentally associated signal-to-interference variability in low-frequency active sonar" will be presented at the 146th meeting of the Acoustical Society of America, November 2003 in Austin, TX.

RESULTS

The main objective of these ACT I signal excess studies was to characterize environmentally induced variability of low frequency active sonar signal-to-interference ratio in a demonstrably well-behaved continental shelf environment, first, because such environments are representative of many operational areas of interest, but also because such a well-behaved scenario constitutes a baseline for more environmentally stressing scenarios and areas. The ACT I test was conducted in an area of homogenous sand-silt-clay bottom composition, in water of 180 m depth with less than 1/8 deg bottom slope. The winds during ACT I were less than 5 kts and the sea state was between 0 and 1 Beaufort.

Generalizing the principal result of the analysis is that there is a measurable variability in signal-to-interference ratio associated with the environment, even when very quiescent conditions prevail. For ACT I this variability is summarized in Table 1.

Table 1. Measured variability of 100-500 Hz signal-to-interference for ACT I reverberation limited condition. Also shown is target-to-receiver (26 km) observed transmission loss variability.

Quantity	Standard Deviation [dB]
Signal-to-Interference (temporal)	1.6
Signal-to-Interference (spatial)	2.0
Target/Receiver Transmission Loss	1.1

In these measurements there was no apparent correlation between the variability of target-to-receiver transmission loss and the ping-to-ping variability of signal-to-interference ratio. In addition there was no observed systematic dependence of signal-to-interference variability and experiment geometry (note that the echo repeater "target" used in this experiment provides an azimuthally omni-directional response, so that target bistatic effects do not enter this idealized experimental setup).

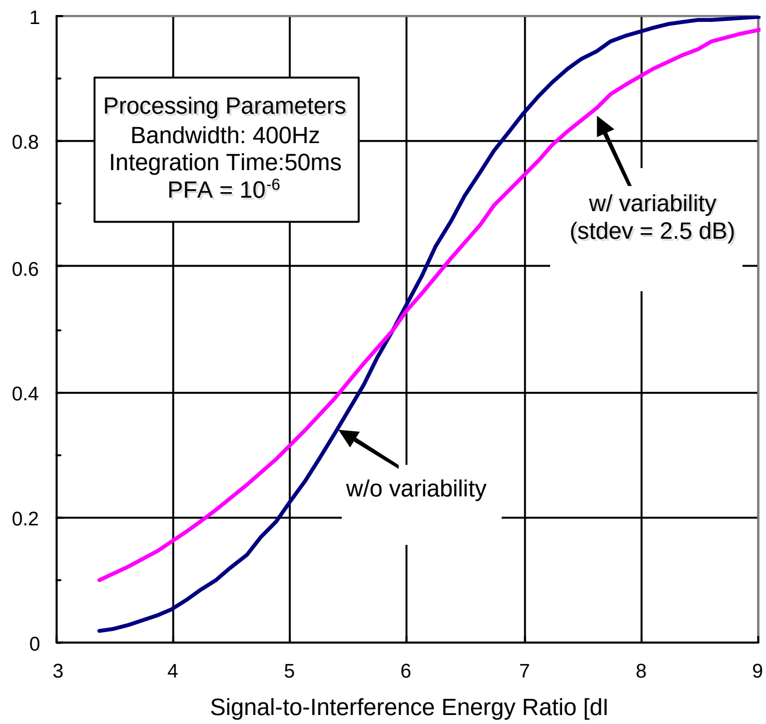

Figure 1. Effect of environmental variability as observed in ACT I on detection performance [2].

The results of this experiment provide insight into the irreducible variability that can be associated with the environment in low frequency active sonar. The potential physical sources (such as transmission loss variability) responsible for this variability in received signal-to-background is the subject of our current investigations under this program. The effect of this environmentally induced variability on detection performance is shown in Figure 1. These results are based on the detection performance model presented in [2]. It should be reiterated that the results presented do not include the effect of echo variability associated with target strength aspect angle dependence.

IMPACT/APPLICATIONS

There is a Fleet concern that performance prediction and tactical decision aids (TDA) are often not reliable because of the inherent uncertainty associated with the TDA inputs. The impact of the current work will be to identify the sources of uncertainty (whether from intrinsic variability or unknown end-to-end parameters) for low frequency broadband active sonars and to reduce, to the extent possible, the unknown to intrinsic variability. The application will be to TDA improvements for such systems as DT and IEER.

RELATED PROJECTS

This project is part of the UNITES project and is coordinated and linked with the other efforts under the UNITES team. Other related projects include the other programs under the ONR Code 32 Department Research Initiative (DRI) on the effect of acoustic environmental uncertainty on the performance of Navy systems. Reference to this program and these projects can be found at the following website: http://www.onr.navy.mil/sci_tech/chief/cuwg/default.htm

REFERENCES

[1] A. Papoulis, *Probability, Random Variables and Stochastic Processes*, p 197, McGraw-Hill, NY, 1965

[2] P.G. Cable, “On Distant Thunder Detection Index”, BBN Technical Memorandum (Nov. 1999)